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UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF ENTOMOLOGY AND PLANT QUARANTINE

Project Date Author

TITLE

SUBJECT—

A STUDY OF CLIMATIC INFLUENCES ON TIMBER LOSSES CAUSED BY INSECTS IN THE PONDEROSA PINE TYPE OF NORTHERN CALIFORNIA FOR THE SEASON OF 1939

by
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Berkeley, California
March 14, 1940

U. S. GOVERNMENT PRINTING OFFICE 8—9742

INDEX NO.—

Forest Insect Laboratory
Berkeley, California
March 14, 1940

A STUDY OF CLIMATIC INFLUENCES ON TIMBER LOSSES CAUSED BY INSECTS IN THE PONDEROSA PINE TYPE OF NORTHERN CALIFORNIA FOR THE SEASON OF 1939

Report of Progress

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A STUDY OF CLIMATIC INFLUENCES ON TIMBER LOSSES CAUSED BY INSECTS IN THE PONDEROSA PINE TYPE OF NORTHERN CALIFORNIA FOR THE SEASON OF 1939

INTRODUCTION

The theory has long been held by various investigators that climatic factors are related to timber losses caused by the western pine beetle and associated insects in the ponderosa pine forests of northern California. It is logical to expect that such a relationship does exist, for these factors are known to affect all forms of life, and are known to be intimately associated with insects injurious to agricultural crops. However, attempts to use such records as are available from Weather Bureau stations have failed to show any consistent relationship between climatic factors and insect caused losses in timber stands.

One of the most serious obstacles in the analysis of this problem in the past has been the dearth of accurate information on precipitation and other climatic factors in the forested areas of this country. This situation is particularly acute in the thinly populated area of northeastern California, where timber losses have been so severe during the past two decades. In Modoc County, which covers an area of approximately 4,750 square miles, for example, there are but two permanent Weather Bureau stations where continuous records have been maintained during the past twenty years. These two stations, at Fort Bidwell and Cedarville, are both in non-timbered areas at the extreme eastern edge of the county and approximately 75 miles from areas where timber losses have been most severe. Thornthwaite, et al. (14) have shown that all storms possess basically similar structural characteristics, each having one or more nuclei of high rainfall intensity and large precipitation amounts which diminish as one approaches the periphery. Therefore, the chances that two raingages, in an area of 4,750 square miles, would give a reliable average for the area is exceedingly remote.

Before intelligent recommendations can be made for the control of the western pine beetle and similar insects, through variations in management practices, it is essential that a better understanding be obtained of the effects of climatic and other ecological factors on both the insects and the forest. Since this understanding cannot be obtained through analyses of existing records, chiefly because climatic records are not available for forested areas where losses are occuring, it has become necessary to set up in the forest a special study of these factors in relation to damage.

OBJECTIVES

The primary objectives of this study are:

1. To determine if there are quantitative differences in climatic or other ecological factors which are associated with differences in timber losses caused by insects in the ponderosa pine type of northeastern California.

2. To determine which of these factors appear to be most dominant in their effect upon:

   a. The western pine beetle and other associated insects, directly.

   b. The host tree, and indirectly the insect.

3. To determine if these factors can be utilized to predict future fluctuations in timber loss.

HISTORICAL

There has been very little intensive published work on this important problem from the standpoint of forest insects. As early as 1909 Hopkins (9), in discussing factors favorable and unfavorable for the development of barkbeetles, summed up his impressions on this subject, which were based upon general observations, as follows: "It is evident, therefore, that drought is not an important factor in contributing to the multiplication and destructiveness of this class of insects " (western barkbeetles). In this same paper he reported the direct effect of low temperatures on the southern pine barkbeetle, when the extremely cold winter of 1902-3 was given credit for complete extermination of this insect in the state of Virginia.

In 1914, Felt (7) reported an outbreak of the hickory bark beetle in the vicinity of New York City, which occurred in 1908. He showed that this outbreak was associated with a definite deficiency in precipitation in 1906 and several years preceding.

This was follwed ten years later, in 1924 by Blackman's (3) fairly comprehensive paper on his study of the effect of precipitation on the hickory barkbeetle. In this article, he pointed out deficiencies in rainfall for several years preceding the epidemic of 1912 in the vicinity of Syracuse, N. Y. In 1915 there was a considerable excess in precipitation which apparently reduced this infestation to an endemic state. He also reported a heavy mortality of adults, during feeding and egg laying, brought about directly by heavy rains.

This was followed by Craighead's (5) intensive appraisal of the effect of precipitation on the southern pine beetle, in 1925. He showed a close correlation between rainfall records at existing Weather Bureau Stations, in the Southeast, and epidemics of this insect. This correlation was particularly striking in the case of late summer and fall deficiencies in precipitation.

In 1931, Blackman (4) in his paper on the black hills beetle, reported that he could find no striking correlation between existing rainfall records and outbreaks of this barkbeetle. He suggested that this lack of correlation might be due to using rainfall records from existing weather bureau stations in non-timbered prairie country, many miles distant from areas where timber losses were occurring in the timbered mountains. Blackman, however, did point out a very close relationship between bark moisture and survival of broods of this barkbeetle.

In 1931, Miller (12) pointed out that low temperatures had a direct lethal effect on the western pine beetle. He demonstrated by laboratory technique that partial mortality occurs at a temperature of 0 degrees F. with practically complete mortality at temperatures between -10 and -18 degrees F. Later in 1933 (13) he reported high field mortality of the western pine beetle in Northeastern California caused by temperatures as low as -19 degrees in December 1932. The average mortality due to this freeze was approximately 65%. Other investigators working on the western pine beetle have since recorded similar losses due to low temperatures.

Keen (11), in 1938 made an outstanding contribution to our knowledge of the broad, long-time, effects of climate on tree growth, and pointed out a significant correlation between seasonal precipitation and annual growth in ponderosa pine. He, together with Antevs (1), has found a marked deficiency in precipitation prevailing in the ponderosa pine belt in Northeastern California and Eastern Oregon, since 1917. This deficiency is generally reflected in sub-normal tree growth during that period. However there appears to be no marked, consistent, correlation between years of excessive rainfall deficiency and years of peak losses by the western pine beetle, as might be expected. There is, however, a general trend of years of high losses associated with years of precipitation deficiencies over a long period.

It is at once apparent that most of the previous workers have been considering only one factor of climate, that of precipitation, and have not considered the other factors of temperature, light, and evaporation, or the interaction of these factors with precipitation. Almost without exception it has been necessary for previous investigators to utilize records from Weather Bureau stations, often times in non-timbered areas and many miles from the scene of insect activity, which, specifically, may account for the lack of association of climatic factors and timber losses caused by the western pine beetle. Therefore, in the present study, climatic factors will be measured right out in the woods where losses are occurring.

SCOPE OF THE STUDY

In the initiation of a problem of this character a brief review of some of the factors, expected to be of importance, might be timely. These include temperature, humidity, precipitation, evaporation, light and radiation, atmospheric pressure and wind movement as these are all known to affect, either directly or indirectly both the insect and the host (Uvarov, 15, 16).

On the principle that the approach to a problem of this nature should proceed from the specific to the general, initial work has been started on a relatively small unit of approximately 250,000 acres of forest in which are represented most of the mixtures and degrees of loss common to ponderosa pine stands of northeastern California. The early work is exploratory in nature and designed to develop standard methods and techniques for evaluating the various factors. It is expected that if significant differences can be shown in the factors operating in various parts of this small area, it will be later possible to confirm or supplement these findings by studies extended over a much wider area.

This study deals primarily with insects, which during their developmental period are confined to the cambium region of coniferous trees, chiefly ponderosa pine. During the adult stage, however, they are free flyers, and apparently are capable of migrating up to distances as great as two miles from the tree from which they emerged. During their developmental period they are subject to effects of climate, both direct and indirect; the factors directly affecting this stage are temperature, humidity, and atmospheric pressure. Those indirectly affecting them would be any climatic factor which would affect the host tree. In the adult stage factors expected to affect them would include temperature, light and radiation, humidity, and precipitation (rain, hail, or snow).

The dominant tree species under consideration in this study is ponderosa pine. It is generally agreed among foresters and ecologists that moisture is a definite limiting factor in the growth of this tree. Also it is a tree species which has been most generally used for interpreting past and present climatic cycles because of its accurate reflection, in ring growth, of climatic effects, Antevs (1), Douglas (6), Glock (8) and Keen (11).

METHOD OF STUDY

Since the timber stands in the Burney area have already been classified by Johnson (10) according to four insect hazard zones, the present study has been set up to utilize these zones as fully as possible. The method of study is to measure, observe, and analyse in each zone the various climatic, and ecological factors involved. Investigations are now underway on the following points:

1. Climate
2. Soil
3. Western pine beetle populations
4. Tree growth
5. Losses in timber stands

A weather station to measure the various climatic factors, throughout the growing season of the tree, and period of activity of the insect, was established in each of four different hazard zones. In addition a complete weather station was established at the Hat Creek Laboratory for continuous all year records (Figure 1). Figure 2 shows the location of these weather stations with reference to the different hazard zones. These are designated as follows: Warner Bridge, in a hazard V zone; Blue Lake in hazard IV zone; Burney Flat, in hazard III zone; Cornaz Lake, in hazard II zone; and the Hat Creek Station, in hazard IV zone.

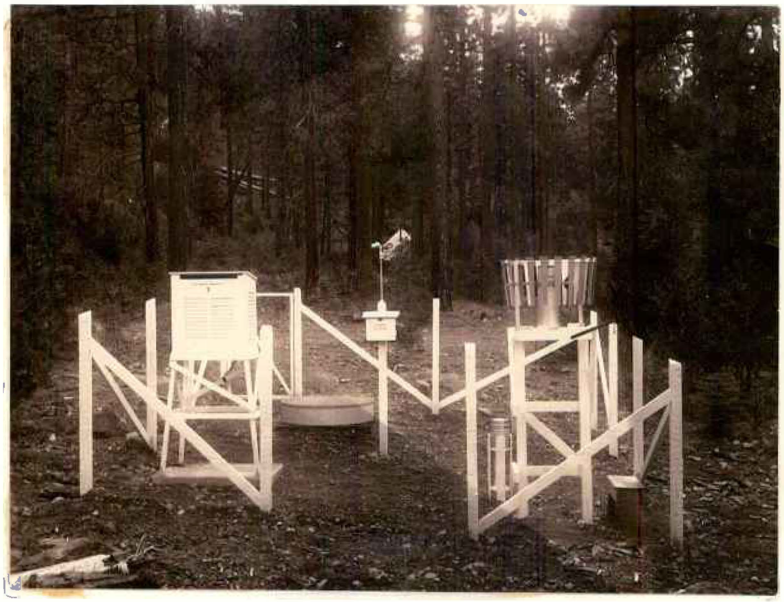
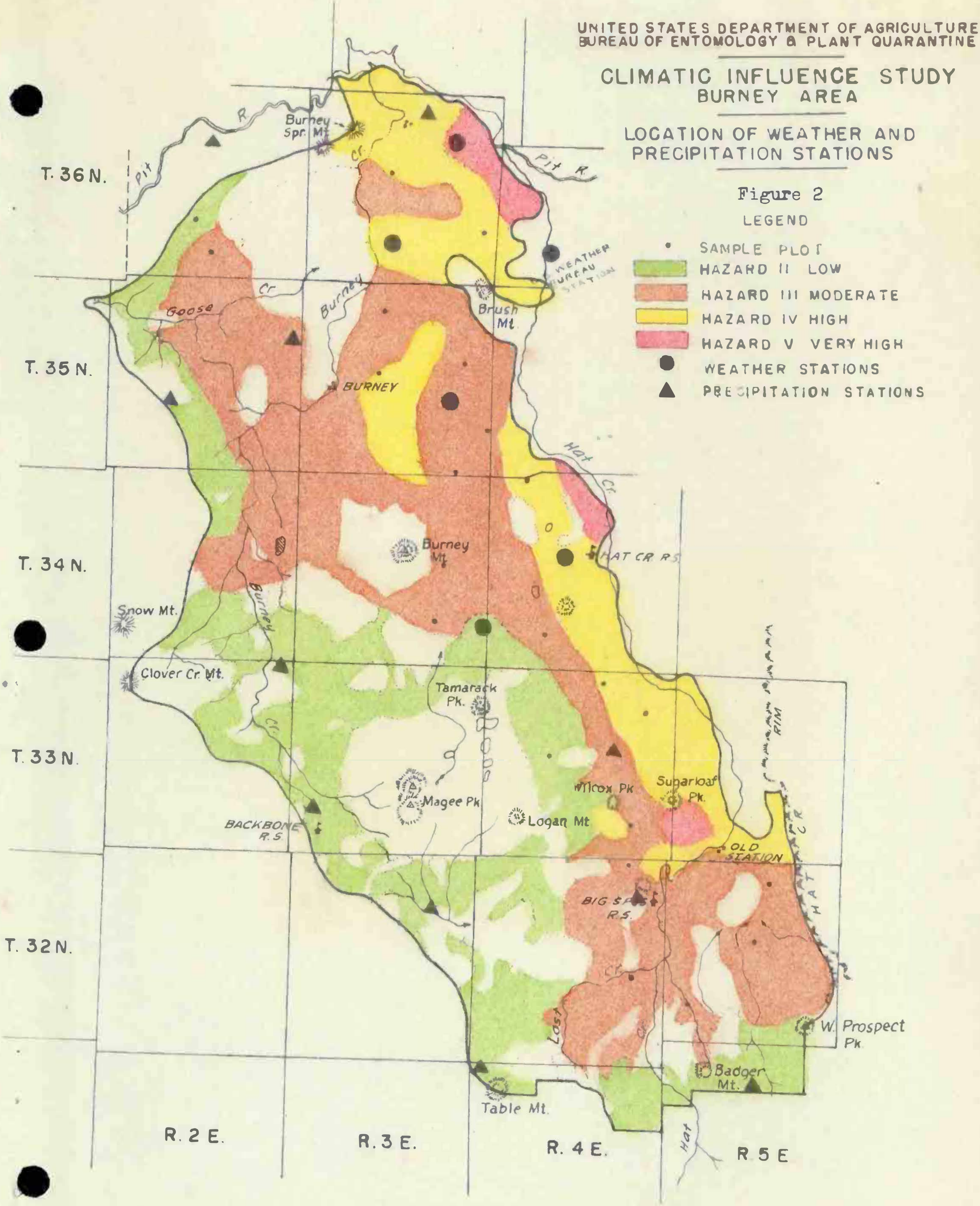


Figure 1

Weather Station at the Hat Creek Field Laboratory, equipped with rain and snow gages, hygrothermographs, soil thermograph, anemometer, evaporation pan, seepage tank, maximum and minimum air and soil thermometers.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CLIMATIC INFLUENCE STUDY
BURNEY AREA
LOCATION OF WEATHER AND PRECIPITATION STATIONS
Figure 2
LEGEND
SAMPLE PLOT
HAZARD II LOW
HAZARD III MODERATE
HAZARD IV HIGH
HAZARD V VERY HIGH
WEATHER STATIONS
PRECIPITATION STATIONS
T. 36 N.
T. 35 N.
T. 34 N.
T. 33 N.
T. 32 N.
R. 2 E.
R. 3 E.
R. 4 E.
R. 5 E
Pit R
Burney Spr. Mt.
Cr.
Pit R.
WEATHER BUREAU STATION
Goose Cr.
Burney
Brush Mt.
BURNEY
Hat Cr.
Burney Mt.
HAT CR. R.S.
Snow Mt.
Burney
Clover Cr. Mt.
Cr.
Tamarack Pk.
RIM
Wilcox Pk
Sugarloaf Pk.
Magee Pk
Logan Mt
BACKBONE R.S.
OLD STATION
HAT CR
BIG SPGS R.S.
Cr.
Lost
W. Prospect Pk.
Badger Mt.
Table Mt.
Hat

The areas used for the weather station establishment were selected as uniform as possible in all respects except insect hazard. All areas are essentially level, of pure ponderosa pine type, and with the exception of Cornaz Lake are at approximately 3,000 feet elevation. The Cornaz Lake station is at an elevation of 4,600 feet.

Timber losses, to form a basis for evaluating climatic effects, are being collected on 50 permanent sample plots distributed at random on the Burney area. A separate report is being prepared on this phase of the problem.

LOCATION AND DESCRIPTION OF THE BURNEY AREA

Location

The Burney Area of approximately 250,000 acres is located in southeastern Shasta County, and includes, roughly, townships 32 to 36 north and ranges 2 to 5 east. It comprises the three watersheds of the Hat, Burney and Goose creeks, which are all tributaries of the Pit River. This area is bordered on the south by the Lassen National Park; on the east by the Hat Creek lava rim; on the north, by Lake Britton and the Pit River; and on the west by a ridge extending from Hatchet Mountain to Clover Mountain and Table Mountain. The headquarters for the study is located at the Hat Creek Field Laboratory. See Figure 7.

Timber Resources and Types

Johnson (10) reports approximately 4 billion board feet of timber on 169,000 timbered acres in this area. This is made up of slightly more than half of three needled pine, principally, ponderosa pine, with the following species making up the balance, listed in order of their abundance: white fir, sugar pine, incense cedar, Douglas fir, lodgepole pine and red fir.

Types range from those very tolerant of dry site conditions to those which are very exacting in their moisture requirements. Eastern fringe areas are principally Digger pine, oak, and ponderosa pine, which soon change to pure ponderosa pine which predominates up to elevations of about 5,000 feet. At higher elevations the more mesophytic mixed coniferous type predominates, with ponderosa pine occurring in the mixtures, except in the case of lodgepole pine which usually occurs in pure stands. Timber resources by species and hazard zones are available from Johnson's report (10).

Topographic Features

This area is characterized by considerable variation in topography. Elevations range from about 3,000 feet on the Burney Flat to over 10,000 feet

on Lassen Peak. There are seven mountain peaks within the area over 7,000 feet and four over 8,000 feet. A considerable portion of the area to the north comprises a large flat where the elevation averages about 3,100 feet. This is the area north of Burney Mountain. The area south of this mountain is generally rugged mountain country with many peaks and few level areas. These ranges are part of the Main Cascade Range and are all of volcanic origin, including Mt. Lassen which is the only active volcano in the United States.

Climatic Features

The average precipitation for the Hat Creek weather bureau station the only one in the area, is approximately 20 inches annually. However, as this station is in a non-timbered area at an elevation of 2,990 feet at the extreme eastern edge of the Burney area, it is expected that this does not furnish a representative mean of the whole area. Rather it is expected to represent the minimum. The precipitation in this area is definitely seasonal with approximately 80 percent of the total annual precipitation occurring during the six winter months. A major portion of this precipitation occurs in the form of snow which often persists, at high altitudes, well into the summer. In 1938 snow remained on Lassen, McGee and Burney throughout the entire year. This precipitation stored in the form of snow, which is released gradually throughout the early growing season, is expected to have an important bearing on this study and will be studied along with other factors. It probably would be difficult to find a more variable area of equal size in the ponderosa pine belt, with respect to precipitation. In 1938, for example, the California Cooperative Snow Surveys showed a snow pack of 282 inches on Mt. Lassen at an elevation of 8,400 feet, on April 1. This represented a rainfall equivalent of 153 inches compared to 19 inches of precipitation for the same period Oct. 1 to April 1 at the Hat Creek Station less than 30 miles away.

The mean annual maximum temperature for the Hat Creek Station is 65 and the minimum is 35. The highest summer temperature recorded for this area is 110 and the minimum winter temperature is -20. The average date of the last killing frost is June 1, and the first killing frost in the fall is Sept. 1, but killing frosts can be expected every month except July.

The summer months are characterized by usually clear and bright days with low humidity and moderately high temperatures. There is practically no rain during the summer months except that which comes in the form of occasional thunder storms.

Wind movement is generally persistent from the south and while rarely strong is nevertheless prevalent throughout the day with little movement at night.

MEASUREMENT OF FACTORS AND RESULTS OF THE 1939 STUDY

The initial work of the first season was of necessity exploratory in nature, and consisted principally of the testing of various instruments and methods for measuring climatic factors thought to be important in the ecology of timber stands and/or of the insects causing timber losses; and a method of sampling insect losses.

This study was initiated on April 13, but because of the lack of several important instruments, complete records are not available for all factors throughout the season. Those which are most nearly complete include air temperature, soil temperature, soil moisture, evaporation, and precipitation. As the majority of instruments selected for this work are of the weekly recording or registering type it was decided to make observations on a weekly basis. This schedule was adhered to throughout the season with the single exception of soil moisture where the period was extended to biweekly during the latter part of the season.

In a problem of this nature the results of one season's work are not expected to more than offer indications of trends, particularly as much of these data are incomplete for the season, for the reason of not having sufficient instruments with which to equip the stations until late in the season. Therefore, the results reported below must be considered as definitely preliminary. Nevertheless in some cases they tend to show significant micro-climatic differences between local areas of different hazard classification. Climatic site factors which were found to differ significantly include, air temperature, soil temperature at 6" depth, soil moisture at 9" depth, precipitation and evaporation. Factors which were found not to differ significantly were those of tree growth, soil moisture at the surface and 16" depth. The lack of significance in the latter cases is attributed to the small number of samples taken at these depths.

The discussion of the measurement of factors and the results of the 1939 study will be covered under the headings of the primary objectives.

Objective 1. To determine if there are quantitative differences in climatic or other ecological factors which are associated with differences in timber losses caused by insects in the ponderosa pine type of northeastern California.

Climatic Factors

In order to evaluate climatic factors, complete weather stations conforming to standards set by the U. S. Weather Bureau, have been established in each of the four hazard zones, with the additional master station at the Hat Creek Field Laboratory (Figure 1). During 1940 the four standard stations will be operated from March 15 to November 1, while the Hat Creek Station will be operated all year. Observations are made each Monday, at which time, charts are changed and checks made on the accuracy of all recording instruments. The factors measured at each station include air temperature, precipitation, relative humidity, soil temperature and moisture, and evaporation.

Air Temperature: Air temperature records were obtained by the use of recording thermographs of the standard Weather Bureau type, with charts covering a weekly period. Continuous records for 1939 were maintained at only the two stations representing the extremes of hazard, that of II and V. These records will be taken at all stations, however, in 1940.

The results of the 1939 study have shown that air temperature differs in a very highly significant manner between hazard II and hazard V with the average daily temperature being 56.6 in II and 62.9 in V (Figure 3 and Table I). Temperature is expected to have an important bearing on this problem because it affects, both directly and indirectly, practically all of the physiological processes of the host tree and associated insects. Therefore the difference of an average daily temperature of 6 degrees is expected to be of practical significance. This difference was reflected in the time of initiation and cessation of height and diameter growth on these two areas, with growth starting about two weeks later on hazard II and continuing almost a month after growth had stopped on hazard V. This temperature difference was further reflected in the number of generations of the western pine beetle which developed on both areas. On hazard II there were but two and a quarter generations compared to three and a quarter on hazard V.

Soil Temperature: Continuous recorded soil temperature at 6" was maintained throughout the season at the weather stations in hazard II and V. zones. These records will be maintained at all stations during 1940. This factor was found to differ in a highly significant manner between the two hazards, with the average daily temperature being 57.9 in hazard II and 65.7 in hazard V (Table I). Soil temperatures are believed to greatly influence root activity and growth of the whole plant. As in the case of air temperature the difference between hazards is believed to have practical significance.

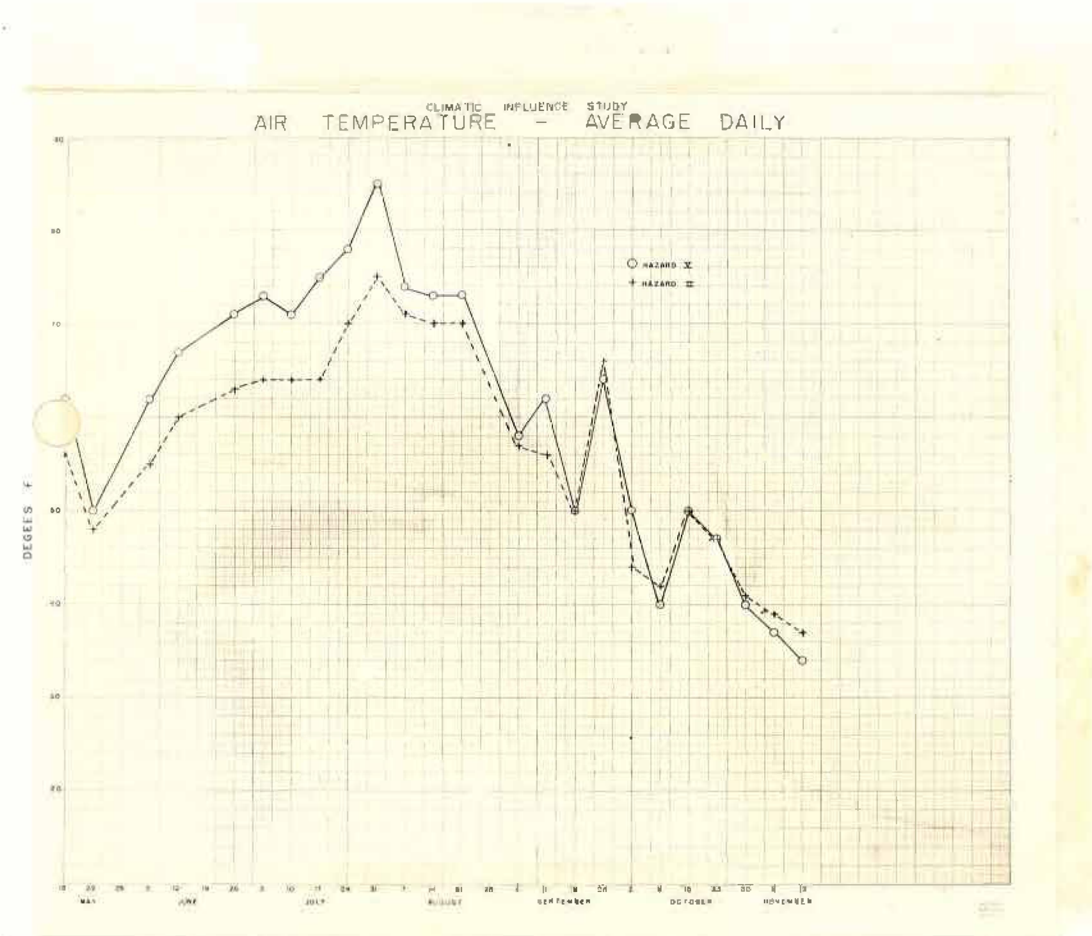


Figure 3

Fluctuation of average daily air temperature on hazard II and hazard V zones for the 1939 season.

TABLE I. Statistical Table for the 1939 Climatic Study

Site Factor		By Hazard II	III	IV	V	F Found	F at .05	F at .01	Significance*
Average Daily Air Temperature	°F.	56.6			62.9	116.6	4.4	8.3	V.H.S.
Average Daily Soil Temperature	°F. at 6"	57.9			65.7	25.1	4.2	7.6	V.H.S.
Average Weekly Soil Moisture	% at 9"	17.1	16.2	15.6	15.8	4.9	3.1	5.0	S.
Precipitation Total	Seasonal[1] (in.)	19.4	17.9	16.9	15.0	7.0	2.7	4.1	H.S.
	Fall[2] (in.)	3.1	2.5	2.1	1.8	8.8	3.1	4.9	H.S.
Evaporation Total	4/13 - 8/21 (in.)	27.8			35.5	93.0	4.5	8.7	V.H.S.
	8/21 -10/2 (in.)	12.3			7.7	7.0	6.6	16.3	S.
Tree Growth	Height (in.)	.38			.36	1.0	4.5	8.5	N.S.
	Circumference (in.)	.45			.35	3.6	5.3	11.3	N.S.
Generations D.B.	No.	2¼			3¼				

1--Records for four permanent stations, April 1939 through January 1940.
2--Records for sixteen temporary precipitation stations, September 9 to October 31, 1939.
*--S-Significant; H.S.-Highly Significant; V.H.S.-Very Highly Significant; N.S.-Not Significant.

Soil Moisture: Considerable data were collected on this phase of the problem during the past field season. Weekly samples of eight each were taken from each area in the vicinity of the weather stations during the first half of the field season. These were extended to bi-weekly during the last half of the season after it was found that the soil moisture level had reached a more or less stable low point. A series of eight samples was selected, on the basis of preliminary sampling, as the number needed to yield a mean value with a sampling error of only 2.5 percent of the mean. This means that if an average soil moisture for eight samples was 10 percent, the chances were 20 to 1 that the true mean of this area would lie between 9.5 and 10.5 percent.

The average weekly soil moisture at a depth of 9 inches was found to be 17.1 for hazard II, 16.2 for hazard III, 15.6 for hazard IV and 15.8 for hazard V (table I). The trends in these differences are statistically significant, but not highly so. However it was observed that there was a marked difference in the physical structure and color of the soils on the different hazards. The soil on hazard II, for example, tends definitely toward a fine sand, while that on hazard V, has a definite clay structure. Due to our knowledge of wilting coefficient, where with pure sand it is about 1.5 percent while in clay it is about 15 percent, it is expected that at low soil moisture levels moisture would be available in the sandy soil in hazard II, and probably non-available in the clay soil in hazard V. During 1940 it is planned to analyze all soils for wilting coefficient, water holding capacity, together with general physical characters. When this information has been collected a further analysis of soil moisture data will be made.

Figure 4 shows the trend in soil moisture at the different hazard zones throughout the season. From this it may be noted that there was considerable difference between hazards in the spring and fall, but little difference during mid-summer.

Late in August twenty of the survey plots were sampled for soil moisture to determine if any marked differences in soil moisture could be observed between areas of different hazards as a check on the records obtained at the weather stations. In general there was fair agreement between hazard zones and soil moisture, but there was one very marked exception as may be noted in figure 5. In the northern part of the area there was good agreement with the areas of high hazard yielding the lowest soil moisture percent. However in the southern part of the area there was a complete reversal with the low hazard areas yielding the lowest soil moisture percent. Again the character of the soil in these two regions may be radically different and will be studied during 1940.

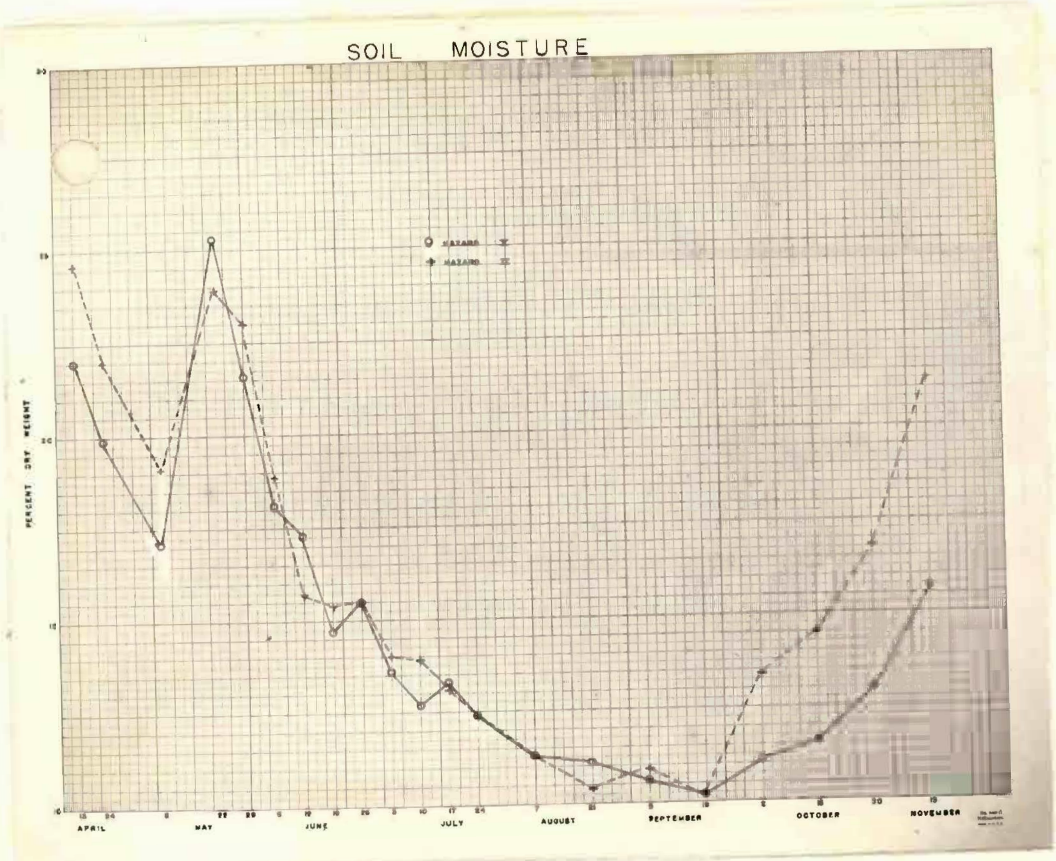
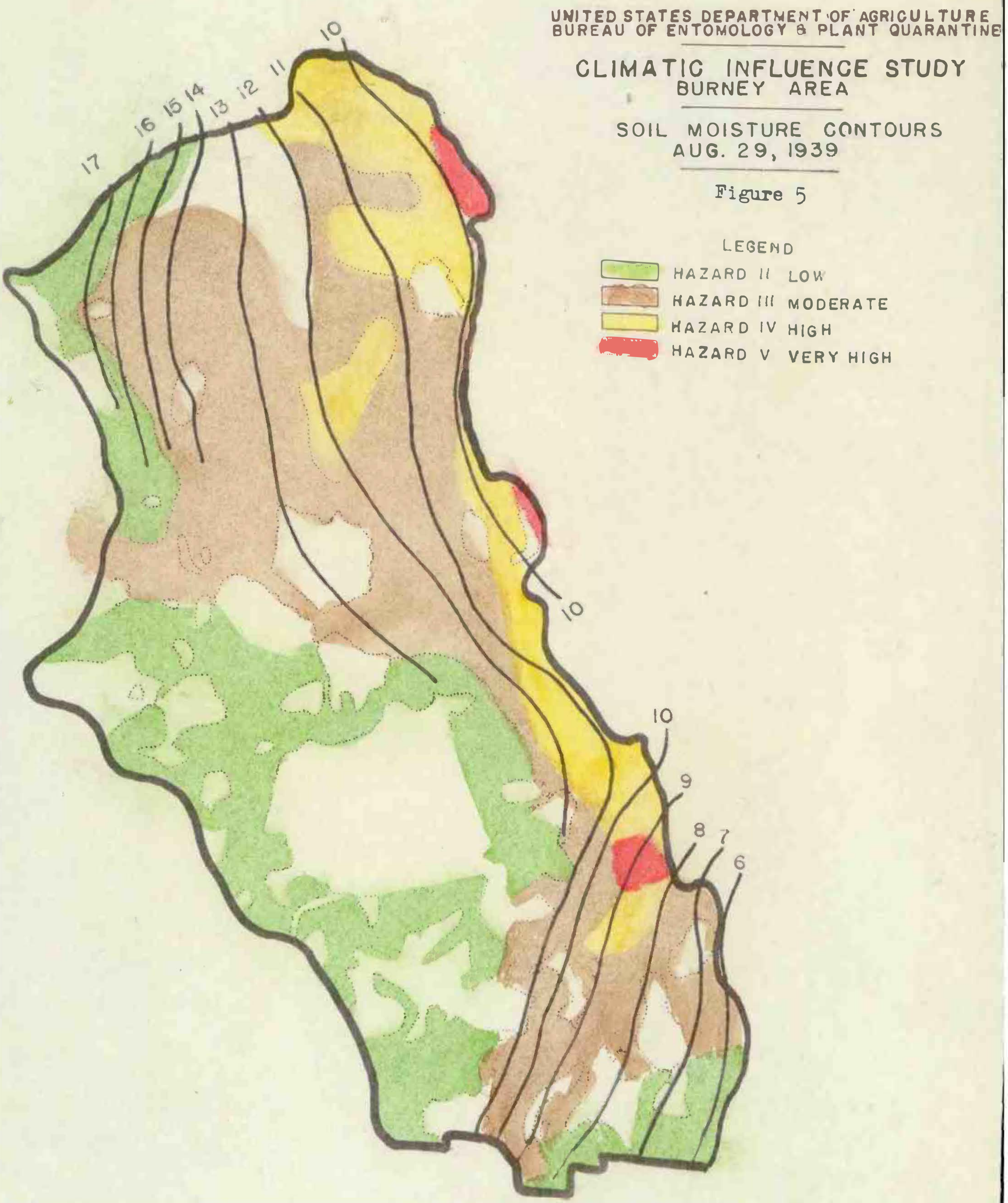


Figure 4

Fluctuation in soil moisture at a 9 inch depth in Hazard II and Hazard V zones for the season of 1939.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CLIMATIC INFLUENCE STUDY
BURNEY AREA
SOIL MOISTURE CONTOURS
AUG. 29, 1939
Figure 5
LEGEND
HAZARD II LOW
HAZARD III MODERATE
HAZARD IV HIGH
HAZARD V VERY HIGH
17
16
15
14
13
12
11
10
10
10
9
8
7
6

Precipitation: Inasmuch as precipitation in this area comes both in the form of rain and snow it was necessary to plan our program so as to measure both forms. Rainfall records were obtained by the use of the standard Fire Weather Study Gages used in this region. As these were read at weekly intervals it was necessary to put a small amount of light oil in each gage to prevent evaporation. In addition to the total seasonal records obtained at the five weather stations information was also collected on fall precipitation over the Burney area as a whole. This was accomplished by the random distribution of 11 additional gages (figure 2). These fall precipitation stations were maintained from September 15 to October 31. In view of the information obtained from these during that period it is planned to maintain these throughout the season in the future.

Precipitation in the form of snow is measured in two ways. The first is by the installation of a shielded metal storage snow gage which has been developed by S. A. Alter of the Weather Bureau of Salt Lake City. This consists of a standard 8" rain gage supported on a platform, with a series of metal leaves or wings surrounding the gage to reduce updraughts and eddying effects of the wind. (Figure 6). This gage is equipped with a "charge" of calcium

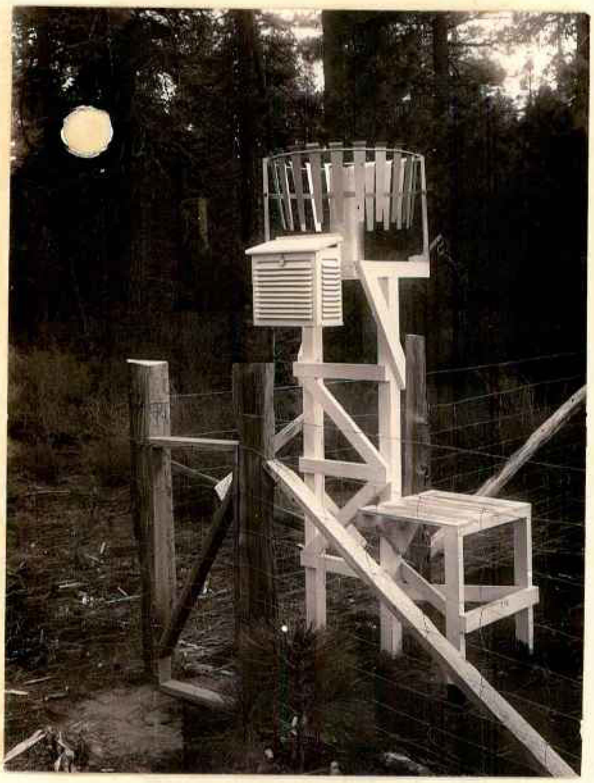


Figure 6

Storage shielded snow gage of the Alter Type, with maximum and minimum air thermomether shelter for winter reocrds. Snow gage is "charged" with a solution of calcium chloride for the purpose of melting the snow and to prevent freezing. Light oil is added to the mixture to prevent evaporation.

chloride which acts both as a melting agent and as an anti-freeze. This solution immediately reduces snow to water and prevents subsequent freezing of the solution. Eight ounces of light turbine oil are added to the solution to prevent evaporation. The can and charge are weighed at the beginning of the period and again at the end and the difference in weight is then converted to inches precipitation by the use of conversion tables. These gages are read once a month during the winter and recharged if found necessary. The second method of snow measurement is the standard method developed by the California Cooperative Snow Surveys and consists of sampling snow depth and density at predetermined points on a snow course. This usually represents a traverse of from 500 to 1000 feet along which samples are taken at uniform spacing with a minimum of ten samples along each course. As the present Cooperative Snow Surveys did not cover much of the Burney area it was necessary to establish additional courses to get this information. Therefore upon advice of the California Cooperative Snow Survey we have established seven snow courses in the Burney area to supplement the records taken by other observers. A course was established at each of the permanent weather stations and two additional courses put in where we plan to maintain permanent precipitation records in the future. Figure 7 shows the distribution of the snow courses in this area including those established by this study. We are actively cooperating with the California Cooperative Snow Surveys by supplying them with our information, monthly, on these courses and they in turn are cooperating by supplying us with a set of snow sampling equipment, and general and specific published information on the snow surveys in this region.

The trend in partial seasonal precipitation is shown in figure 8. No significant differences were observed between hazards during the spring and summer months as may be noted in table IIa. However the fall and winter records have shown a significant trend by different hazard zones as may be noted in table IIb. The totals for the different hazard zones for the period of October 1 to February 1 were as follows: hazard II, 14.8"; hazard III, 13.4"; hazard IV, 11.8"; hazard V, 10.8". The differences by hazards for the entire season were found to be highly significant.

The extensive fall precipitation survey at 16 stations throughout the Burney area showed a definite relationship between hazard zones and rainfall. This is illustrated in figure 9. The average by hazards for this period was as follows: hazard II, 3.1"; hazard III, 2.5"; hazard IV, 2.1"; and hazard V, 1.8". As in the case of winter precipitation at the four major stations this extensive fall survey showed differences in precipitation which are highly significant. During 1940 it is planned to establish premanent precipitation stations at points where fall records were taken.

Snow Surveys: The winter to date has been unusually mild with greater than normal precipitation but this has practically all come in the form of rain, with little or no snow below elevations of 5,000 feet. The snow surveys conducted on January 1 and February 1, showed no snow on any of the seven courses with the exception of the Ashpan Butte course where approximately 5 inches was measured in February. Had the winter precipitation been normal in the form of snow it is expected that most of the courses would

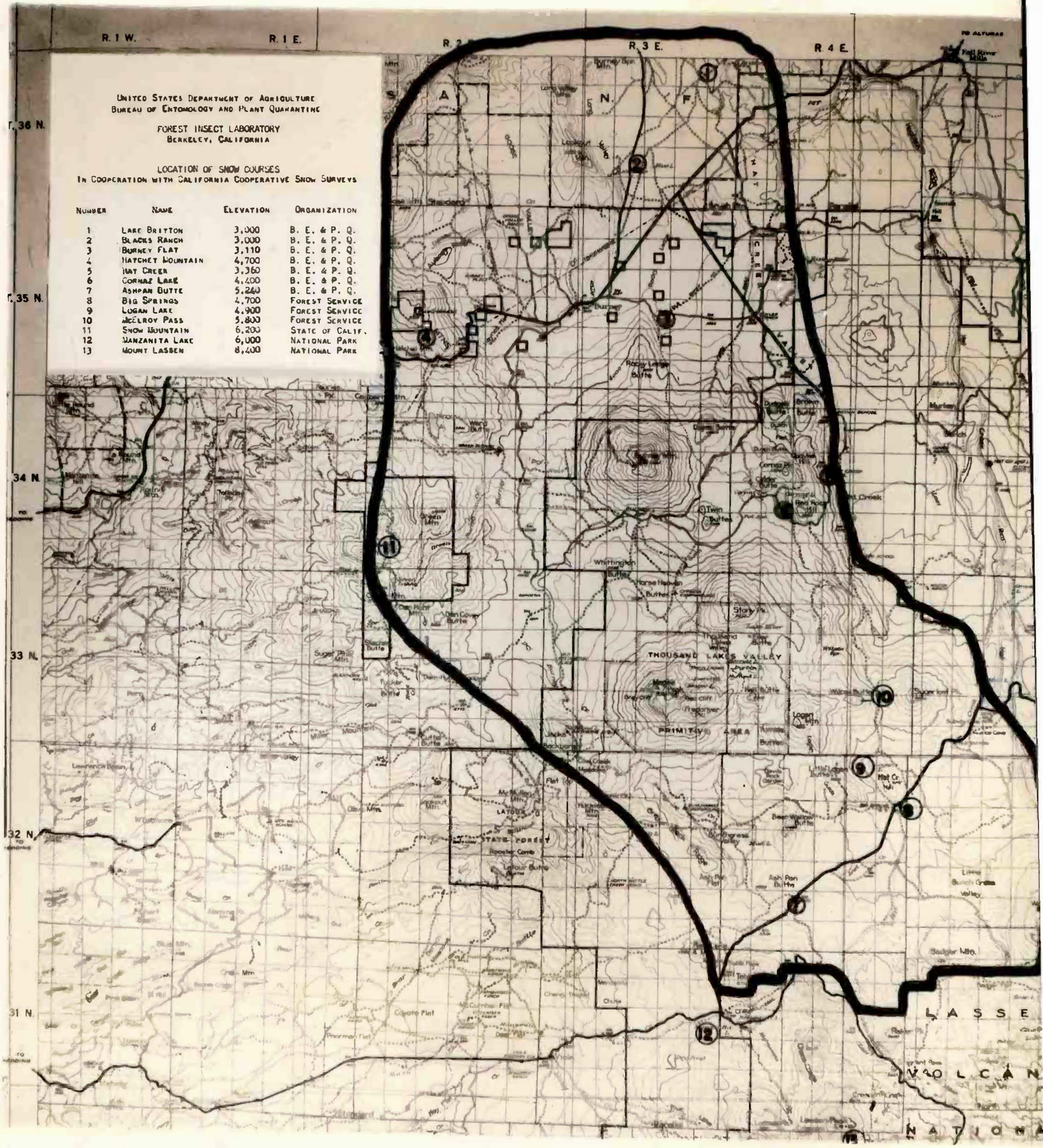

R. 1 W.
R. 1 E.
R. 3 E.
R. 4 E.
T. 36 N.
T. 35 N.
34 N.
33 N.
32 N.
31 N.
United States Department of Agriculture
Bureau of Entomology and Plant Quarantine
FOREST INSECT LABORATORY
Berkeley, California
LOCATION OF SNOW COURSES
In Cooperation with California Cooperative Snow Surveys
Number Name Elevation Organization
1 Lake Britton 3,000 B. E. & P. Q.
2 Blacks Ranch 3,000 B. E. & P. Q.
3 Burney Flat 3,110 B. E. & P. Q.
4 Hatchet Mountain 4,700 B. E. & P. Q.
5 Hat Creek 3,360 B. E. & P. Q.
6 Cornaz Lake 4,400 B. E. & P. Q.
7 Ashpan Butte 5,240 B. E. & P. Q.
8 Big Springs 4,700 Forest Service
9 Logan Lake 4,900 Forest Service
10 McElroy Pass 5,800 Forest Service
11 Snow Mountain 6,200 State of Calif.
12 Manzanita Lake 6,000 National Park
13 Mount Lassen 8,400 National Park
THOUSAND LAKES VALLEY
PRIMITIVE AREA
STATE FOREST

Figure 7

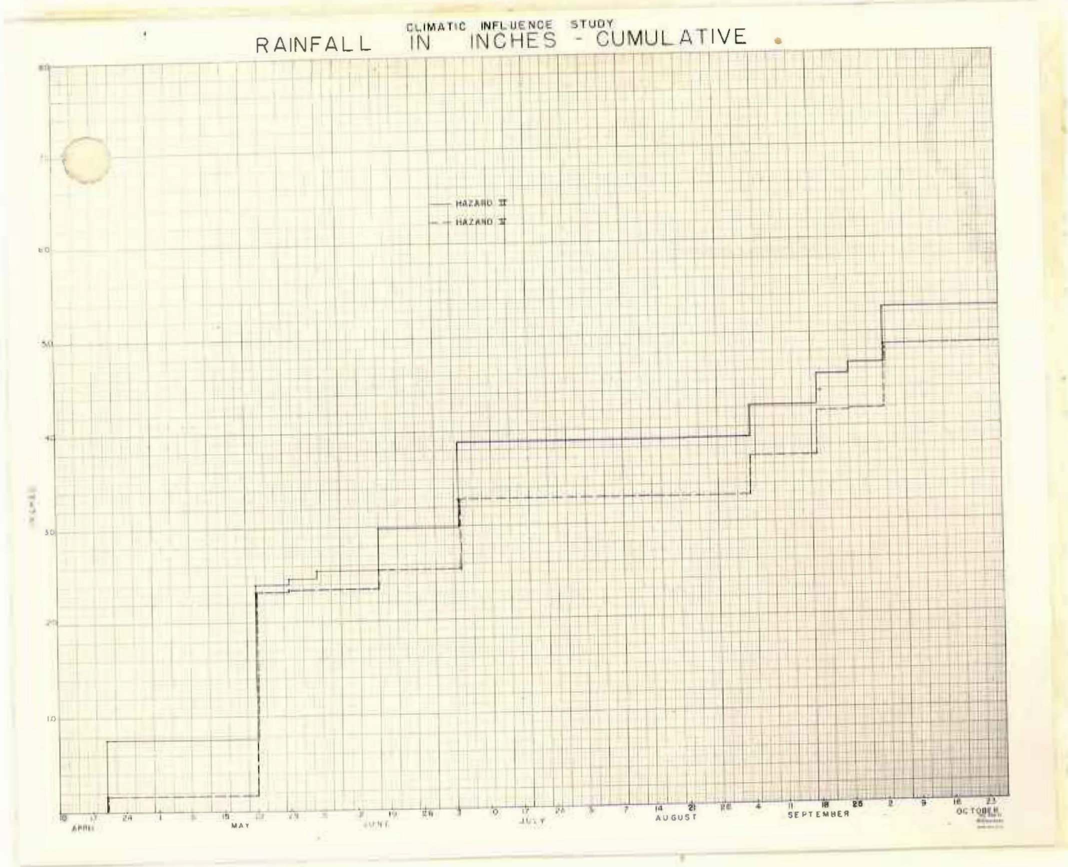


Figure 8

Precipitation chart for Hazard II and Hazard V zones for the 1939 season.

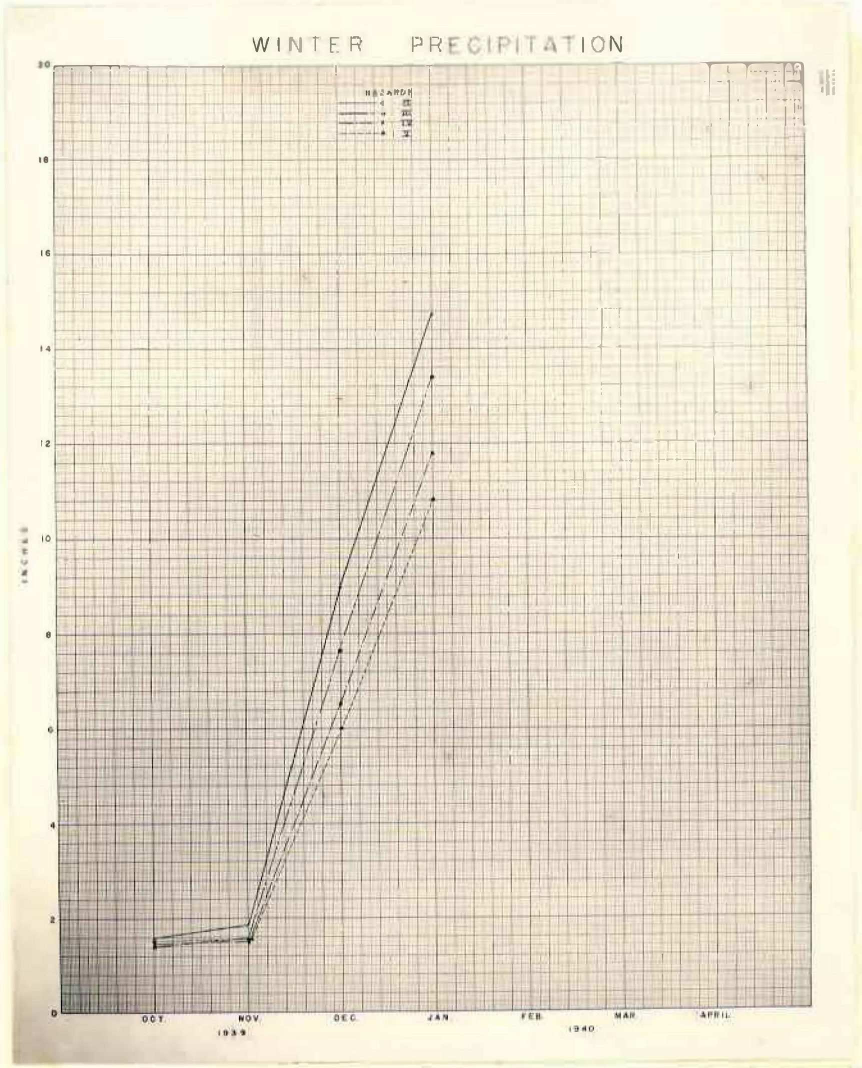


Figure 5a

Winter precipitation chart for four hazard zones.

TABLE II. Comparison of Precipitation by Hazard Zones in Inches

Period	Hazard II Cornaz Lake	Hazard III Burney Flat	Hazard IV Blue Lake	Hazard V Warner Bridge
a.				
April	.58	.44	.32	.17
May	1.89	1.92	2.35	2.19
June	.51	.48	.22	.17
July	.93	.70	.89	.75
August	.09	.01	.01	004
September	.68	.95	1.27	.91
Total spring and summer	4.68	4.50	5.06	4.23
b.				
October	1.59	1.41	1.46	1.55
November	.24	.14	.03	.00
December	7.11	6.08	5.02	4.47
January	5.81	5.81	5.33	4.81
Total fall and winter	14.75	13.44	11.84	10.83
Total April to January	19.43	17.94	16.90	15.06

UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF ENTOMOLOGY & PLANT QUARANTINE

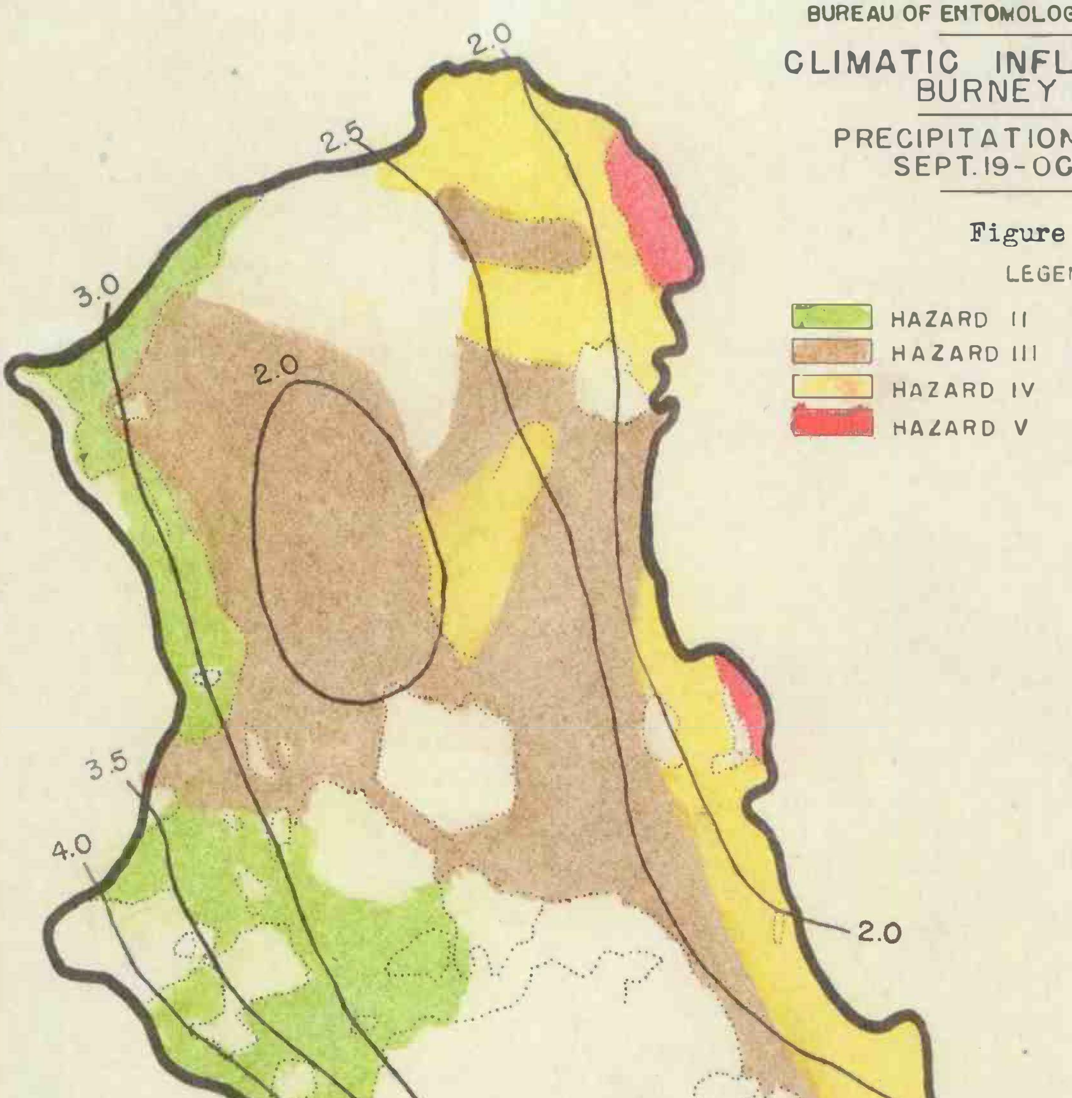
CLIMATIC INFLUENCE STUDY
BURNEY AREA

PRECIPITATION CONTOURS
SEPT. 19 - OCT. 31, 1939

Figure 9

LEGEND

HAZARD II LOW
HAZARD III MODERATE
HAZARD IV HIGH
HAZARD V VERY HIGH



have had in excess of ten feet on February 1. On February 1 the Cooperative Snow Survey reports showed that the Mt. Lassen snow course, at an elevation of 8,400 feet, had 105 inches of snow with a water equivalent of 48 inches. Unless this deficiency of stored moisture in the form of snow, at low elevations, is made up during the balance of the winter, it is expected that this will have a marked effect on available moisture during the 1940 growing season.

Evaporation: Evaporation from an open pan was found to differ in a highly significant manner between hazard II and hazard V (Table 1 and Figure 10). From April 13 to August 21, the weekly evaporation at hazard V

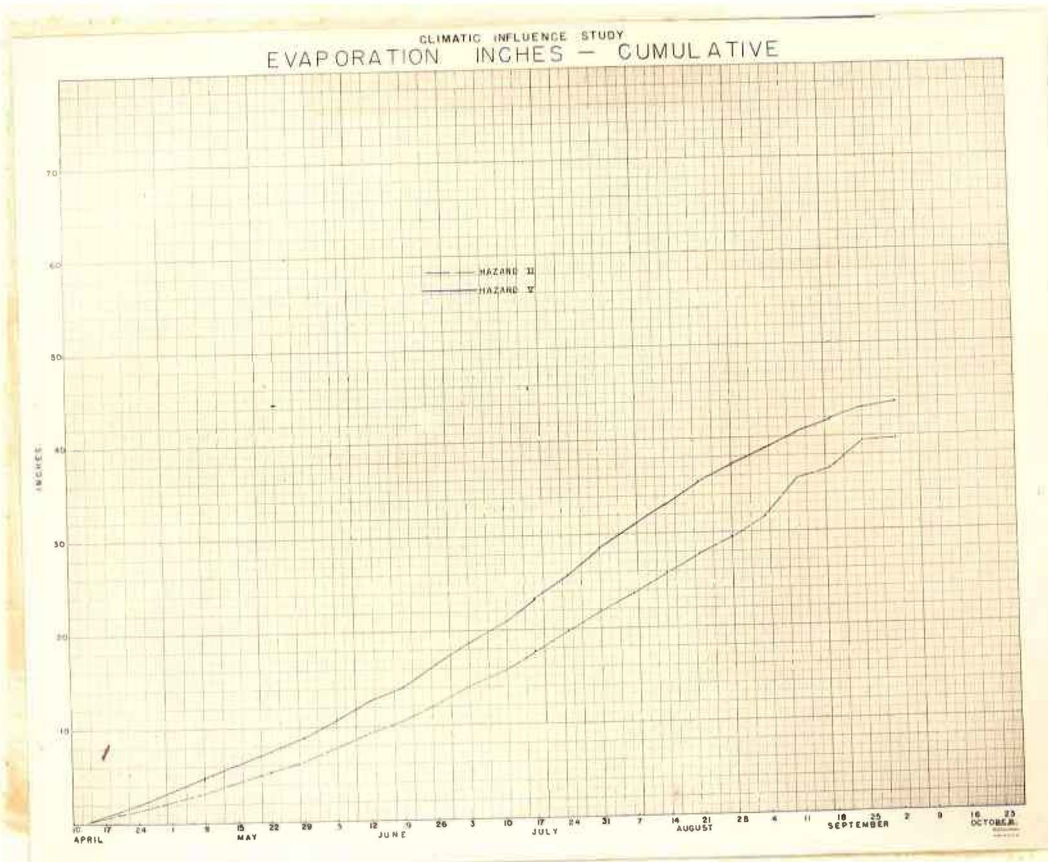


Figure 10.

Evaporation for the season of 1939 in Hazard II and Hazard V zones.

was consistently about 1.3 times that in hazard II with the total for the period being 35.5 for V and 27.8 for II. However, it was noted after August 21 that there was a sudden reversal in ratios with evaporation being higher in II than in V. At the same time, Eaton observed a great abundance of wasps of the species Vespula pennsylvanicus, drinking from the evaporation pan at the hazard II station. The activity of these insects apparently accounted for this reversal in evaporation ratios, as no other factor such as temperature, showed a corresponding reversal. This disturbing factor will be eliminated in the 1940 study by shielding all gages by screen to prevent access by insects.

Seepage: A specially constructed seepage tank has been developed for this study to measure the amount of precipitation which actually enters the soil. This should furnish an index of the effective precipitation, with the difference between the catch in the seepage tank and that which falls as snow or rain representing that portion lost through evaporation or run-off (Figure 11).

Figure 11.

Seepage tank installed at each weather station. Water passing through surface soil is trapped and measured in underground tank.

Relative Humidity: Relative humidity of the air was not measured during 1939 except for a short period at the Hat Creek Station. However, this factor will be measured at all stations during 1940, using the standard Weather Bureau hygrograph.

Light: Light also was not measured during 1939, but will probably be measured in 1940, at least the duration of sunlight at the Hat Creek Station.

Wind Movement: Partial records of wind movement were maintained at the Hat Creek Station during the latter part of the 1939 season and will be continued during 1940 (Figure 12).

Figure 12.

Recording type of anemometer installed at the Hat Creek Station.

Objective 2. To determine which of the climatic factors appear to be most dominant in their effect upon:
A. The western pine beetle, directly.
B. The host tree and indirectly the western pine beetle.

A. The Western Pine Beetle

It is obvious that it would be impossible in this study, with the resources at out command, to consider each insect species in detail, which is associated with timber losses. For this reason the present study is specifically confined to a detailed consideration of the species considered to be the most important, the western pine beetle. The reasons for selecting this insect for study, may be summed up as follows:

1. The western pine beetle is the most abundant species found in the whole timber loss complex in the ponderosa pine type. It occurs, almost without exception, either alone or with other insects, in every ponderosa pine tree killed by insects.

2. It appears to be the most dominant insect species associated with years of peak losses and grouping.

3. It is known to respond directly to temperautre effects in its developmental period and will continue to produce successive generations so long as temperature factors are favorable. That is, it appears not to have any resting period during its development other than that brought about by low temperatures.

4. It is known that extremes of temperatures, both high and low, have a lethal effect on the brood while it is working in standing trees.

5. It can be more easily manipulated than any of the other associated species in inducing forced attacks.

6. The groundwork for conducting population studies has been pretty well developed.

Generations: Due to the pressure of other duties, observations on the number of generations of the western pine beetle was the only phase of the work attempted during 1939. However, in 1940, detailed work will also be conducted on population studies.

These observational data indicated that there is a definite difference in the number of generations of bark beetles produced on the two areas. Hazard II area produced only two and a quarter generations while

hazard V had three and a quarter. To further check this point on the number of generations of the western pine beetle, forced attack studies will be carried on in 1940. Material containing identical stages of the western pine broods will be caged on three trees in each zone early in the spring and development followed through successive generations, transferring cages to additional trees as necessary for the balance of the season.

Sampling Barkbeetle Populations: In order to be able to evaluate the effects of climatic and other factors on barkbeetle abundance, it is necessary to develop direct methods for sampling population. A study will be made during 1940 to determine, both by counts and by the use of tree cages, the attack-emergence ratio for each generation. It is expected that if this ratio can be accurately measured it may serve as a useful basis in predicting fluctuations in timber loss. Investigations will be made of the distribution of the population on various sides and at various heights in infested trees.

B. Tree Studies

Height Growth: Height growth was measured periodically on five ponderosa pine trees in the two extreme hazard zones. The results of this study have shown very little difference in height growth for the 1939 season. The average height was .38" on hazard II, compared to .36" on hazard V. This difference of .06" proved to be nonsignificant (Figure 13). However, the period of height growth differed markedly in the two areas, with the initiation of growth delayed about two weeks and the cessation of growth prolonged about a month on hazard II (Figure 13). During the 1940 season this study will be expanded to include about 100 trees distributed over 15 permanent sample plots.

Diameter growth was measured weekly during the growing season on five trees each on hazard II and hazard V. These were measured by the use of an aluminum growth band similar to that developed on the locust borer study. The diameter growth on these two areas for 1939 was as follows, hazard II, .14" and hazard V, .11". Again as in the case of height growth, there was no significant difference in these two figures. This study will be expanded to include 100 trees in the same areas as height growth.

Phenological Records: No work was done on this phase of the problem in 1939, but observations will be started on the dominant plant species in the vicinity of the weather stations in 1940 to determine if there is any consistent correlation between weather data and this factor.

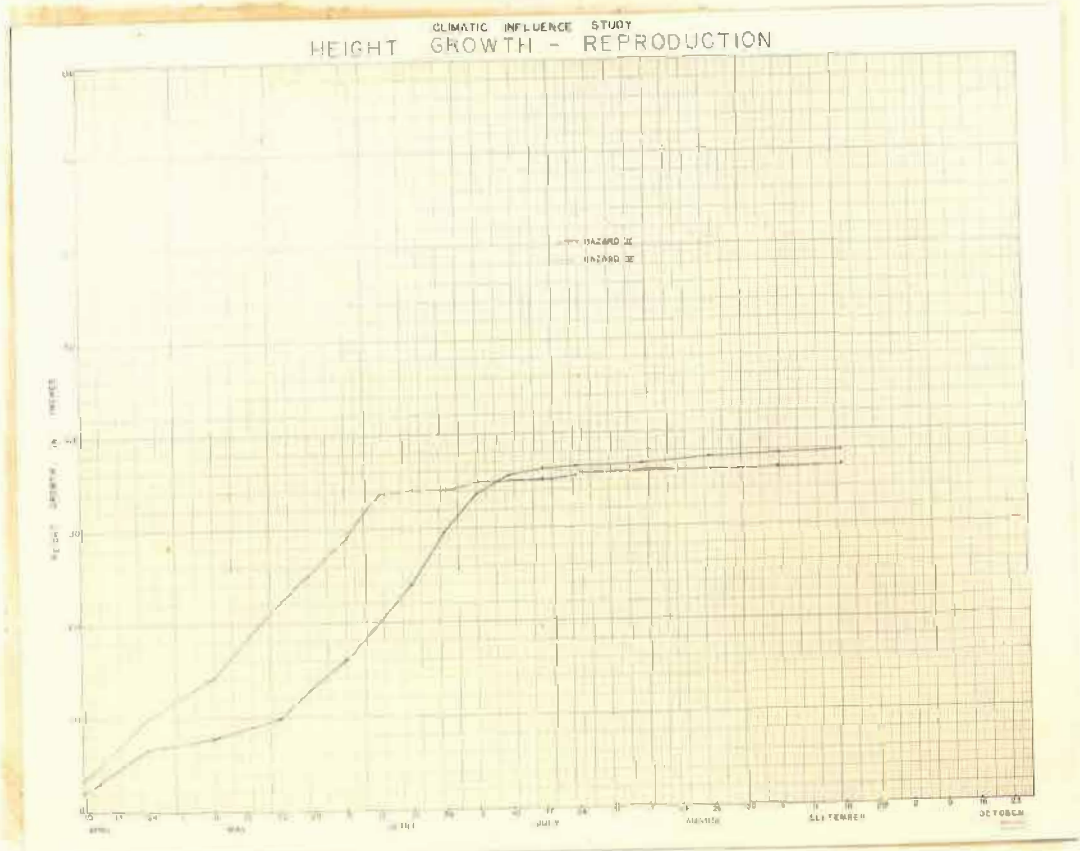


Figure 13.

Fluctuation of average height growth on 5 seedlings on each of two hazard areas, II and V, for the 1939 season.

Objective 3. To determine if these factors can be utilized to predict future fluctuations in timber loss.

Partial seasonal records of climatic data for one year are not expected to furnish a basis for any logical prediction of future losses, particularly as we have been unable to evaluate these various effects, to date. Therefore it will probably be several years before we can begin to use these data by themselves for predicting purposes. However, past losses in the Modoc and the eastern Lassen have shown what appears to be a definite, regular cyclic tendency, with the cycle extending for approximately seven years (Figure 14). It may be that this cycle can be utilized together with climatic data to predict fluctuations in loss. The cycle principle alone was used in 1938 with success in predicting the increase in loss in 1939 on the Modoc, Shasta and Lassen areas. The results of a prediction for one year, however, mean little as the chances of success would be a 50-50 ratio on a random guess. It is only after a series of successful predictions are attained, that credit can be given to a system. This system will be used annually until something better is devised in order to test its effectiveness.

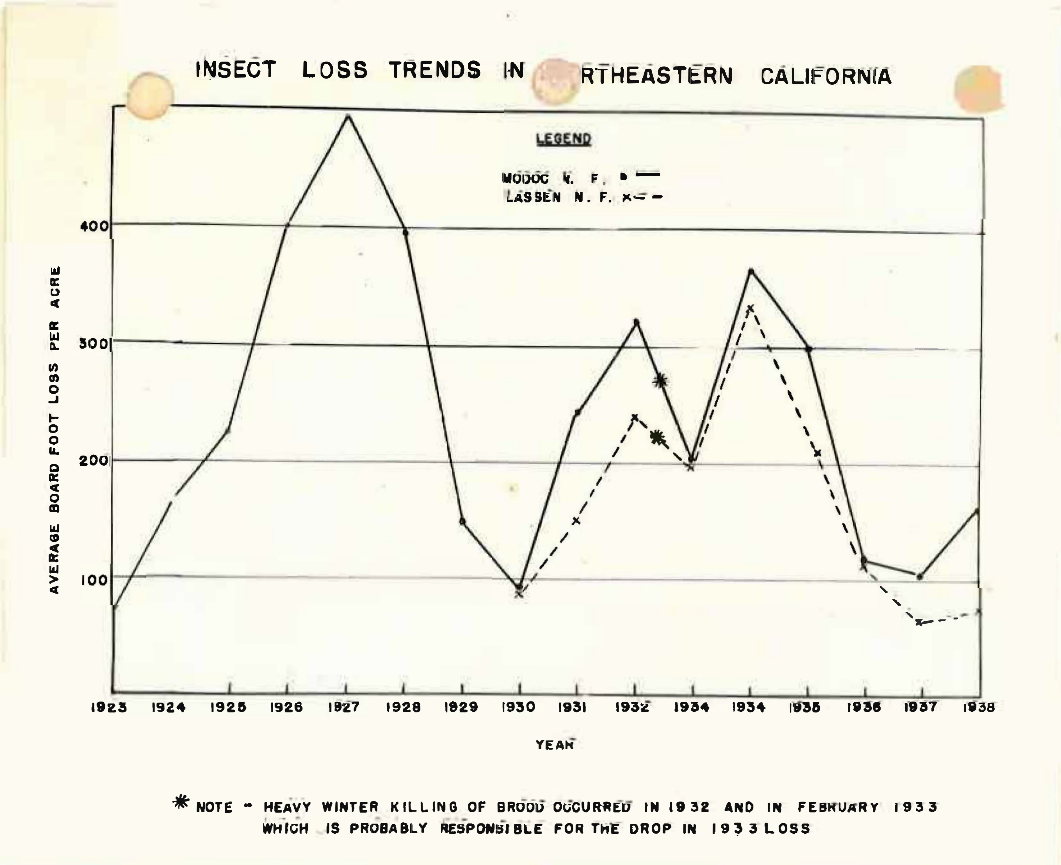


Figure 14.

Annual fluctuation in insect caused timber losses which have demonstrated cyclic tendencies. Losses in 1939 exceed those for 1938, indicating another rising cycle.

SUMMARY

A study to determine if there are quantatative differences in climatic or other ecological factors which are associated with differences in timber losses caused by insects in the ponderosa pine type of northeastern California was initiated on April 15, 1939. On the principle that the approach to this problem should proceed from the specific to the general, initial work was started on a unit of 250,000 acres of forest in Shasta County, known as the Burney Area, which was classified for hazard in 1938. The present study was set up to utilize the hazard zones as fully as possible.

The method of study was to measure, observe and analyze in each zone the various climatic, ecological and biotic factors involved. Investigations were made on the following points.

1. Climate
2. Soil
3. Western pine beetle populations
4. Tree growth
5. Losses in timber stands

In order to evaluate climatic factors, complete weather stations, conforming to standards set by the U. S. Weather Bureau, have been established in each of four hazard zones, with an additional master station at the Hat Creek Field Laboratory.

Only partial records were maintained for many of the factors during 1939 due to lack of instruments early in the season. However, in 1940 complete records will be maintained for all stations throughout the season from March 15 to November 1, and at the Hat Creek Station throughout the year.

Preliminary results from the first season's work indicate the following:

1. That there is a significant difference in the following factors between areas of extreme hazard.
    a. Air temperature
    b. Soil temperature
    c. Fall and winter precipitation
    d. Soil moisture at 9" depth
    e. Evaporation from an open water surface

2. Factors which showed little difference between hazards include
    a. Tree growth
    b. Soil moisture at the surface and at 16", although this may be due to inadequate sampling.
    c. Summer precipitation.

3. That there is a marked difference in the number of generations of the western pine beetle, there being:
   a. In hazard V, three and a quarter generations
   b. In hazard II, two and a quarter generations

4. That there is a marked difference in the date of initiation and cessation of both height and diameter growth between hazard V and hazard II.

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